SUPPORTING INFORMATION
for
How Urban Water Management Prepares for Emerging Opportunities and Threats: Digital Transformation, Ubiquitous Sensing, New Data Sources, and Beyond – a Horizon Scan

Authors: Frank Blumensaat[a,b], João P. Leitão[a], Christoph Ort[a,]*, Jörg Rieckermann[a], Andreas Scheidegger[a], Peter A. Vanrolleghem[c,d], Kris Villez[a]

Affiliations

[a] Eawag, Swiss Federal Institute of Aquatic Science and Technology, Überlandstrasse 133, 8600 Dübendorf, Switzerland

[b] Institute of Environmental Engineering, Chair of Urban Water Systems, ETH Zurich, Stefano-Franscini-Platz 5, 8093 Zurich, Switzerland

[c] modelEAU, Université Laval, Département de génie civil et de génie des eaux, 1065 av. de la Médecine, Québec, QC, G1V 0A6, Canada

[d] CentrEau, Université Laval, 1065 av. de la Médecine, Québec, QC, G1V 0A6, Canada

* corresponding author

Content page

SI 1 Online Survey **S2**
SI 2 Participants and summary statistics **S26**
SI 3 Response behavior of respondents........ **S27**
SI 4 Responses for scenarios *Vision2030* **S29**
SI 5 Summary of comments from survey........ **S30**
SI 6 Responses for importance and familiarity **S41**
SI 7 Correlation analysis to discuss thematic proximity **S43**
SI 8 Data base with all responses ....**doi will be provided in proofs**

SI 1 Online Survey

Introduction to the survey on
'Ubiquitous Monitoring in Storm- and Wastewater'

We condensed 35 emerging topics in six key themes that **may not be widely known** to water professionals but can **have a substantial impact** on the **monitoring and/or management of urban storm- and wastewater systems** in the near future until 2030.

1. **Emerging Data Sources** (8 topics)
2. **Data Management and Modelling** (9 topics)
3. **Interaction between Data and Stakeholders** (6 topics)
4. **New Water Technologies** (4 topics)
5. **New Services** (3 topics)
6. **Societal Values and Implementation** (5 topics)

Thank you for participating!

Peter Vanrolleghem, Frank Blumensaat, Joao Leitao, Christoph Ort,
Jörg Rieckermann, Andreas Scheidegger and Kris Villez.

Theme 1 - Emerging Data Sources

Emerging data sources offer ample opportunities and provide new insights, but they come along with some **challenges**:

i) Increased complexity in data processing, management, and validation
ii) How much data should be collected? Evaluate the trade-off between effort to collect data and information content derived from this data.
iii) Data collection associated to public participation questions the stewardship of the data, and raises privacy and security issues
iv) Difficulty to establish “new-data-approaches” in the (often) norm-referenced thinking of engineering practice

1.1 Onsite High-Resolution Mass Spectrometry

Portable high-resolution mass spectrometers make it possible to observe pollutants on site and in real-time. This can be used for environmental surveillance, understanding of processes and regulation, e.g. industrial polluters/water users.

<u>**Vision2030:**</u> Measure trace pollutants at almost any location at any time in any flux, allowing to increase insights in their fate. It also has the potential to push forward source-control based approaches of pollution management (e.g. polluter-pays principle).

1.2 Autonomous Sensor Platforms and Remote Sensing

Robotized, moving sensor platforms (drones, miniature boats, submersible) are equipped to monitor one or multiple parameters over a water surface or stretch. The platform movement can be passive or active, the latter asking for an objective to steer the movement.

Vision2030: Active and passive robots collect system status information of increased the spatial resolution and consistency. They will reach inaccessible areas and enable a flexible on-demand data collection.

	low … high	
How **familiar** are you with this topic?		☐ n/a
How **important** is this topic for the urban wastewater sector?		☐ n/a
How **realistic** is the example Vision2030?		☐ n/a
How **desirable** is the example Vision2030?		☐ n/a

1.3 Sensing at High Spatial Resolution

Technological advances allow the production of less costly, robust sensors which can be deployed over large territories, or river and sewer stretches. This means data can be collected over wide areas and still at high spatial resolution.

Vision2030: Every manhole is equipped with sensors. The sensor network provides network status information in high spatial resolution and real-time. This allows early warning of floods and storm water events, and results in sewer network management that is efficient, fast, highly adaptive, and reliable.

	low … high	
How **familiar** are you with this topic?		☐ n/a
How **important** is this topic for the urban wastewater sector?		☐ n/a
How **realistic** is the example Vision2030?		☐ n/a
How **desirable** is the example Vision2030?		☐ n/a

1.4 Low-Tech Sensors

Some sensors only provide binary or categorical signals in contrast to sensors designed to provide high-resolution, low-noise, drift-free signals. However, such sensors are cheaper and can be built much more robust than traditional sensors.

Vision2030: Low-tech sensors providing categorical information are placed in sewer networks because they can be operated at low maintenance and energy costs. In combination with a small number of high-quality, continuous sensor signals, these sensors provide fine-grained information across the system.

	low	high	
How **familiar** are you with this topic?			n/a
How **important** is this topic for the urban wastewater sector?			n/a
How **realistic** is the example Vision2030?			n/a
How **desirable** is the example Vision2030?			n/a

1.5 Micropollutant and Pathogen Monitoring

Increasingly sensitive, automated high-throughput analytical methods will be developed to quantify an ever growing number of micropollutants and pathogens – e.g. online flow cytometry – in (waste)water.

Vision2030 Application of these new technologies in monitoring networks will provide ubiquitous data at high spatio-temporal resolution to better understand occurrence and fate of (mixtures of) micropollutants and the changing nature of pathogens (e.g. multi-resistant species). This will facilitate better protection of human and ecosystem health.

	low	high	
How **familiar** are you with this topic?			n/a
How **important** is this topic for the urban wastewater sector?			n/a
How **realistic** is the example Vision2030?			n/a
How **desirable** is the example Vision2030?			n/a

1.6 Environmental DNA

Biological systems release DNA in the environment and current high-throughput amplification technology permits identifying the wealth of organisms present in water systems.

Vision2030: Monitoring of the composition of ecosystems efficiently and at high spatio-temporal resolution, to assess the impact of pollution and different water management strategies on aquatic ecosystems.

low high

How **familiar** are you with this topic? ☐ n/a

How **important** is this topic for the urban wastewater sector? ☐ n/a

How **realistic** is the example Vision2030? ☐ n/a

How **desirable** is the example Vision2030? ☐ n/a

1.7 Implicit Crowd-Sourcing

Individuals and technical systems leave traces of data every day. Such data (e.g. position and temperature of cell-phones, water and energy consumption of households) is routinely collected. This provides a source of spatially distributed information that is not made use of in the water sector today.

Vision2030: A sewage treatment plant obtains forecasts of pollutant loads 3 hours ahead of their arrival at the plant. Forecasts are based on cell-phone data, traffic records and energy consumption rates in the catchment. With this, optimal operational strategies are chosen.

low high

How **familiar** are you with this topic? ☐ n/a

How **important** is this topic for the urban wastewater sector? ☐ n/a

How **realistic** is the example Vision2030? ☐ n/a

How **desirable** is the example Vision2030? ☐ n/a

1.8 Explicit Crowd-Sourcing

By citizen participation obtain information through intrinsically motivated public feedback (e.g. information regarding urban flooding events, pictures, fish kills, algal blooms).

<u>Vision2030:</u> The cleaning of sewer inlets is not (only) done at fixed time intervals, but based on photos which residents send via a smartphone app when they observe a blocked inlet.

low — high

How **familiar** are you with this topic? ☐ n/a

How **important** is this topic for the urban wastewater sector? ☐ n/a

How **realistic** is the example Vision2030? ☐ n/a

How **desirable** is the example Vision2030? ☐ n/a

Theme 2 - Data Management and Modelling

Lots of data are being generated ("**We live in a society bloated with data, yet starved for wisdom**", Elizabeth Kapu'uwailani Lindsey) but tools are needed to make them useful for a wide range of applications (sometimes even unknown at the moment of data collection).
Quality of data is key, e.g. low quality but cheap data can be a huge information source provided the proper (model-based) interpretation is given. However, data without any sense of their quality may lead to risky use, making data quality assessment tools a necessity. Also, indirect data that are augmented by knowledge in the form of relationships and objectives can bring relevant data to the user, and can even be made available for real-time use. Not the quantity of data, but the information content and quality of each data value should be the focus of our attention. And the proper storage of data (and metadata) is essential to make them live for long and available for many water professionals.

2.1 Data Validation

Current manual data quality assessment (often performed by visual inspection) can be replaced by (semi-)automated data validation methods that can handle large (multivariate) data sets and provide some quality index to collected data.

Vision2030: Valuable time and quality of decision-making will be gained by having a quality stamp on each data point. Automatic data validation permits much stronger quality assessments than possible by manual inspection.

	low	high	
How **familiar** are you with this topic?			☐ n/a
How **important** is this topic for the urban wastewater sector?			☐ n/a
How **realistic** is the example Vision2030?			☐ n/a
How **desirable** is the example Vision2030?			☐ n/a

2.2 Metadata Collection and Organization

Efficient collection and storage of data along with proper metadata is increasingly possible. Such metadata describe the status, maintenance record, and deployment record of the sensors that produced the data. This is feasible for a wide range of data sources and distributed systems.

<u>Vision2030:</u> Standards are accepted to define the taxonomy/ontology/organization of metadata for water quality and quantity data warehouses. The re-use of historical data collected over time by different and ageing data collection systems is not only feasible but easy.

	low	high	
How **familiar** are you with this topic?			☐ n/a
How **important** is this topic for the urban wastewater sector?			☐ n/a
How **realistic** is the example Vision2030?			☐ n/a
How **desirable** is the example Vision2030?			☐ n/a

2.3 Optimal Experimental Design

Using a mathematical description of the objective of a measurement campaign or experiment, the experimental conditions (what, where, when, how frequent, how accurate … to measure) are optimized using a model of the system under study.

<u>Vision2030:</u> Models inform how cost- and time-effective measurement campaigns should be conducted to answer the posed measurement question. Data with the highest possible information content for that purpose are obtained.

	low	high	
How **familiar** are you with this topic?			☐ n/a
How **important** is this topic for the urban wastewater sector?			☐ n/a
How **realistic** is the example Vision2030?			☐ n/a
How **desirable** is the example Vision2030?			☐ n/a

2.4 Heterogeneous Data Quality

Very simple sensors can be more robust and energy efficient. However, they may only distinguish a reduced number of categorical states (e.g. wet/dry) or suffer from systematic error or drift. Hence, such measurements require a specific mathematical treatment.

Vision2030: Mathematical methods enable the combination of signals of very different quality. Existing high quality measurements are augmented with a large number of simple, robust sensors to achieve information with a high spatial resolution.

	low	high	
How **familiar** are you with this topic?			☐ n/a
How **important** is this topic for the urban wastewater sector?			☐ n/a
How **realistic** is the example Vision2030?			☐ n/a
How **desirable** is the example Vision2030?			☐ n/a

2.5 Real-Time Models

Fast surrogate models, replacing process-based models, can be updated in real-time to ensure the model description remains close to reality. Model parameter updating (e.g. by an Extended Kalman Filter or back-propagation) is significantly easier than model structure updating.

Vision2030: Models that can guarantee to remain good descriptions of reality can be used for prediction of important variables and thus support better real-time decision-making, e.g. in flood forecasting, real-time control of the sewer system, high-performance control of treatment facilities, etc.

	low	high	
How **familiar** are you with this topic?			☐ n/a
How **important** is this topic for the urban wastewater sector?			☐ n/a
How **realistic** is the example Vision2030?			☐ n/a
How **desirable** is the example Vision2030?			☐ n/a

2.6 Data-Driven Models

Recent research in machine learning goes way beyond classic artificial neural networks and enables to build very complex specific data driven models with limited needs for model structure selection and fine-tuning by experts.

Vision2030: Data-based models are increasingly trusted for tasks previously executed with mechanistic models. Such models require less system understanding, have a higher predictive power, and are updated easily.

	low	high	
How **familiar** are you with this topic?			☐ n/a
How **important** is this topic for the urban wastewater sector?			☐ n/a
How **realistic** is the example Vision2030?			☐ n/a
How **desirable** is the example Vision2030?			☐ n/a

2.7 Goal-Oriented Learning

Reinforcement learning is an approach to train a model to control a complex system in such a way that a long-term goal is achieved. The only requirement is the long-term goal can be evaluated online and fed back into the learning system.

Vision2030: WWTP and sewer systems are automatically operated based on a reinforcement learning algorithm and a predefined objective function. For example, the algorithm ensures that the legal requirements are met with the smallest effort.

	low	high	
How **familiar** are you with this topic?			☐ n/a
How **important** is this topic for the urban wastewater sector?			☐ n/a
How **realistic** is the example Vision2030?			☐ n/a
How **desirable** is the example Vision2030?			☐ n/a

2.8 Software Sensing

A soft sensor uses hard sensor signal(s) and a model to produce a signal that is of relevance to the user.

Vision2030: Software sensing with increasingly advanced models and large data input series allow predicting increasingly relevant decision variables for urban water management and reduce the need for hardware sensors.

	low	high	
How **familiar** are you with this topic?			☐ n/a
How **important** is this topic for the urban wastewater sector?			☐ n/a
How **realistic** is the example Vision2030?			☐ n/a
How **desirable** is the example Vision2030?			☐ n/a

2.9 Linking Aquatic Ecology to Emissions

A relationship between emission patterns, the resulting physico-chemical condition in a receiving water system (including its historical evolution and e.g. morphological boundary conditions) and the aquatic biocenosis which reflects the impact of diverse stressors in an integrated manner.

Vision2030: With a proper model relating emissions and the resulting expected ecosystem, management decisions at the level of the urban wastewater system can be made in view of a desired ecosystem make-up.

	low	high	
How **familiar** are you with this topic?			☐ n/a
How **important** is this topic for the urban wastewater sector?			☐ n/a
How **realistic** is the example Vision2030?			☐ n/a
How **desirable** is the example Vision2030?			☐ n/a

Theme 3 - Interaction between Data and Stakeholders

The stream of data produced today and in the future cannot be handled or exploited any more through conventional means and leads to challenges concerning transparency, trust, operability, and controllability. This drives a demand for specialized tools that aim to organize, optimize, and adapt system understanding. This includes the provision of increasingly automated decision-making solution as well as tools to facilitate the collection of personal data, individual preferences, and expert opinions.

3.1 Ontologies

An ontology is a formal way of describing types, properties, and interrelationships of entities that really or fundamentally exist for a particular domain of discourse . In this context, the domain concerns the urban system with its services (water, electricity, communication, transport,...), city planners, citizens, etc.

Vision2030: Applying the ontology concept to the urban water field defines a common language between the various stakeholders that streamlines planning and maintenance processes and unifies the various viewpoints of the different stakeholders of a living city.


low high

How **familiar** are you with this topic? n/a

How **important** is this topic for the urban wastewater sector? n/a

How **realistic** is the example Vision2030? n/a

How **desirable** is the example Vision2030? n/a

3.2 Augmented Reality

Augmented reality, is a live direct or indirect view of a physical, real-world environment whose elements are augmented by computer-generated sensory input such as sound, video, graphics or GPS data (Wikipedia, 2017).

Vision2030: The possibility of “looking” into the infrastructure hidden underground, or into a reactor/aeration basin, (i) helps city planners knowing system components location, (ii) helps showing the condition of urban water assets to the system managers, and (iii) provides a way to engage with citizens and motivate them for their importance.

	low	high	
How **familiar** are you with this topic?			☐ n/a
How **important** is this topic for the urban wastewater sector?			☐ n/a
How **realistic** is the example Vision2030?			☐ n/a
How **desirable** is the example Vision2030?			☐ n/a

3.3 Serious Games

A serious game or applied game is a game designed for a purpose other than pure entertainment (Wikipedia, 2017).

Vision2030: Serious games are used to motivate the public towards the importance and relevance of urban water systems and resources, as well as to educate professionals. The users develop a more intuitive understanding of complex relationships.

	low	high	
How **familiar** are you with this topic?			☐ n/a
How **important** is this topic for the urban wastewater sector?			☐ n/a
How **realistic** is the example Vision2030?			☐ n/a
How **desirable** is the example Vision2030?			☐ n/a

3.4 Smart Meters and Privacy

Smart meters provide valuable data on the urban water systems. However, such data contain indirectly a lot of information about the lifestyle of individual users. For example, one could identify when people typically return home in the evening, how many people are currently living in a household and so.

Vision2030: Legal regulation require that such data must be protected and only a small number of people have access to it. Data can only be used for predefined purposes.

	low – high	
How **familiar** are you with this topic?		☐ n/a
How **important** is this topic for the urban wastewater sector?		☐ n/a
How **realistic** is the example Vision2030?		☐ n/a
How **desirable** is the example Vision2030?		☐ n/a

3.5 Cyber Security

Wireless data communication, server infrastructure, internet of things and computer controlled systems are vulnerable to accidental malpractice and criminal cyber attacks.

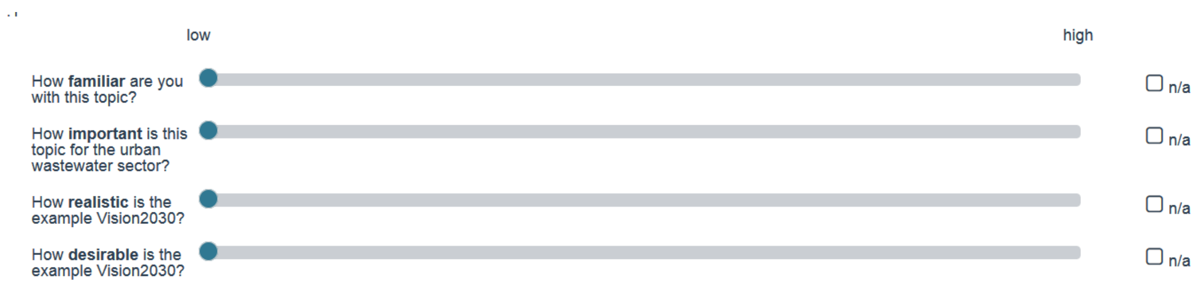
Vision2030: Despite a trend to more digitalisation utilities have not been able to build up enough cyber security expertise to prevent cyber attacks. Being blackmailed by criminals to shut down operation became a realistic threat.

	low – high	
How **familiar** are you with this topic?		☐ n/a
How **important** is this topic for the urban wastewater sector?		☐ n/a
How **realistic** is the example Vision2030?		☐ n/a
How **desirable** is the example Vision2030?		☐ n/a

3.6 Complexity – Blind Trust

The amount of data that is processed to retrieve information for automation has become enormously large. A human operator cannot process this amount of data in real time to control a system. As in aviation, automated solution increasingly handle complex situations with little actual real-life experiential learning opportunities left for human operators.

<u>Vision2030:</u> The occurrence of rare extreme events increasingly challenges available automation systems which have never had learned from rare events. Without the necessary experience and intuition of system behaviours, operators are unable to avoid the catastrophic consequences of such rare events.


low
high
How **familiar** are you with this topic?
n/a
How **important** is this topic for the urban wastewater sector?
n/a
How **realistic** is the example Vision2030?
n/a
How **desirable** is the example Vision2030?
n/a

Theme 4 New Water Technologies

The process units implemented within urban water cycles are increasingly diversified in design and purpose. Primary drivers are increasingly strict demands for and implementations of human and environmental safety regulations. In addition, urban water systems were historically used to satisfy human and environmental protections while today we see a shift to a need to satisfy or trade off multiple objectives simultaneously. Such objectives include human safety, environmental protection, climate change impact reduction, and cost-efficient or even for-profit operation. Achieving these objectives is possible with new process concepts and designs but often requires an adaptive, intelligent, and resilient operation. This drives a demand for increased data collection and improved data quality.

4.1 Decentralization

Several decentralized technologies have been developed, but since operational objectives are formulated at urban, regional, and national scales, centralized operation of decentralized systems is required.

Vision2030: The urban water infrastructure consists of decentralized process units that are controlled intelligently via remote monitoring and centralized operation and optimization. Given that technicians cannot inspect every decentralized unit with the same frequency as is typical for full-scale plants, the decentralized process units are highly autonomous to reduce downtime and maintenance costs.

	low	high	
How **familiar** are you with this topic?			☐ n/a
How **important** is this topic for the urban wastewater sector?			☐ n/a
How **realistic** is the example Vision2030?			☐ n/a
How **desirable** is the example Vision2030?			☐ n/a

4.2 Technology Diversification

Wastewater collection and treatment technologies are increasingly diverse in concept and design, leading to an increased diversity in monitoring and operational challenges in practice, including information flows.

Vision2030: Significantly upgraded data and information management tools assist in handling the knowledge management regarding the ever increasing diversity of technologies that are introduced into the urban-scale wastewater collection and treatment network. Transparent operation and control is feasible through interactive knowledge management and querying.

	low	high	
How **familiar** are you with this topic?			☐ n/a
How **important** is this topic for the urban wastewater sector?			☐ n/a
How **realistic** is the example Vision2030?			☐ n/a
How **desirable** is the example Vision2030?			☐ n/a

4.3 Integrated Management

The water sector shifts away from single-constraint satisfaction (e.g., environmental quality) to multi-objective operation, imposing optimal management of energy, water, and nutrient fluxes at local, regional, national, and global scales. It also includes shifts from emission to immission-based wastewater management, from energy-consuming plants to energy-producing plants, and from pollution removal to resource recovery, all systems that benefit from integrated management.

Vision2030: Measurements of energy, water and nutrient fluxes are available online in real-time. This information allows for integrated management optimizing multiple goals.

	low	high	
How **familiar** are you with this topic?			☐ n/a
How **important** is this topic for the urban wastewater sector?			☐ n/a
How **realistic** is the example Vision2030?			☐ n/a
How **desirable** is the example Vision2030?			☐ n/a

4.4 Data Collected at Personal Resolution

Personal health monitoring devices (fitbit, lab-on-a-chip) and personalized living spaces (Google Nest, …) paint a complete picture of the habits and behaviors of individuals, groups, and populations.

Vision2030: New personalized data, living spaces, and medicine generate an information stream that is used for fine-grained optimization of large and small wastewater infrastructures.

	low	high	
How **familiar** are you with this topic?			☐ n/a
How **important** is this topic for the urban wastewater sector?			☐ n/a
How **realistic** is the example Vision2030?			☐ n/a
How **desirable** is the example Vision2030?			☐ n/a

Theme 5 - New Services

Initially, urban drainage was about improving hygiene in urban areas (get rid of wastewater to avoid pathogens to cause illness directly or via drinking water). With increasingly impervious areas generating surface runoff the next goal was to reduce flooding. Wastewater treatment plants were built to minimize environmental impacts. Nowadays, urban drainage systems can serve for other purposes they were originally not intended for.

5.1 Secondary Health Benefits

Primary health benefits of urban (waste)water systems are flood protection and reduction of water-borne diseases. Secondary health benefits are water security, heat mitigation and landscape planning (stormwater reuse, dual tap system, green infrastructure).

Vision2030: Secondary health benefits are maximized through the design of water-sensitive, more liveable cities, which reduce residents' stress levels.

	low	high	
How **familiar** are you with this topic?			☐ n/a
How **important** is this topic for the urban wastewater sector?			☐ n/a
How **realistic** is the example Vision2030?			☐ n/a
How **desirable** is the example Vision2030?			☐ n/a

5.2 Public Health Information

Wastewater contains a wealth of public health information at the community level of a sewer catchment. Even more personalized information can be collected from smart toilets.

Vision2030: Wastewater is officially used as a source of reliable public health information. Examples are patients' adherence to take meds (toilet as 'doctor at home') or monitoring illicit drug consumption at the community level [sewage-based epidemiology on lifestyle, diet health (obesity levels), …].

	low	high	
How **familiar** are you with this topic?			☐ n/a
How **important** is this topic for the urban wastewater sector?			☐ n/a
How **realistic** is the example Vision2030?			☐ n/a
How **desirable** is the example Vision2030?			☐ n/a

5.3 Resource Recovery

Wastewater-based production of fertilizers (elements N, P, K, S and fibers as soil amendment) and specialty chemicals (isobutanol, lactate, …) that can form the basis of biorefineries. Heat can be recovered as well and energy or energy carriers can be produced from the wastewater organics.

Vision2030: Communities where wastewater is not considered a way to get rid of waterborne diseases and pollution of all kinds, but as a way to transport used water to biorefineries where a maximum of resources is recovered.

Theme 6 - Societal Values and Implementation

Developed societies work by a set of rules (laws and regulations) and indirect mechanisms (insurance and tariffs) to reflect the desired way of living together and within the environment. As society and mentality change, and the values they carry, it can be expected that the legal systems, the deduced regulations, the economic incentives and insurance policies will change as well. The fact that data will be more available, of better quality and covering a wider range of relevant parameters, should allow improved structuring and tuning of legal and economic systems and allow societies to pursue their values more effectively and efficiently.

6.1 Regulations

Regulations have become increasingly stringent through the years (first BOD and TSS, and pathogens, then N and P. More recently micropollutants and microplastics are on the agenda). Regulations are defined in terms of discharge limits or receiving water quality standards.

<u>Vision2030:</u> With increased knowledge on pollutants, more stringent regulations are imposed, increasingly expressed as immission-based pollutant limits (may be variable, depending on environmental conditions) and even human and ecosystem-health related.

6.2 Index-Based Insurances

Providing affordable/effective catastrophe and weather risk insurance to homeowners and small and medium-sized enterprises (SMEs) greatly reduces the vulnerability of an economy to natural disasters. Such insurances can be constructed based on local “risk indices”. For example, the observations of a local weather station, water levels, and local soil geometry and stability can be used to estimate the risk of local flooding or catastrophic soil erosion. These estimates define the premiums.

Vision2030: More localized weather data enables insurances to either avoid “bad risks” or charge them extra premium. This influences land prices as well as living cost in high risk areas.

	low	high	
How **familiar** are you with this topic?			☐ n/a
How **important** is this topic for the urban wastewater sector?			☐ n/a
How **realistic** is the example Vision2030?			☐ n/a
How **desirable** is the example Vision2030?			☐ n/a

6.3 Water Tariffs

Like regulation and insurances, water tariffs are major economic incentives for users of water systems to adapt their system use to a use desired by society.

Vision2030: Variable water tariffs are facilitated through novel monitoring technologies, such as smart meters or toilet use monitors. Using a toilet or runoff from a house connection is priced directly using a smart meter connected to the internet. Prices vary not only with pollution levels, but also depend on weather conditions (potential impact on receiving waters through increased probability of CSOs), and the current state of the local drainage system or the WWTP (overload).

	low	high	
How **familiar** are you with this topic?			☐ n/a
How **important** is this topic for the urban wastewater sector?			☐ n/a
How **realistic** is the example Vision2030?			☐ n/a
How **desirable** is the example Vision2030?			☐ n/a

6.4 Transparent Compliance Assessment

Blockchains can be described as permanent, tamper-proof databases for any kind of data, which are shared by a community and owned by no-one. They could be particularly interesting to environmental surveillance and regulation, because they make it possible to track and verify transactions and interactions even in the absence of a centralized authority.

Vision2030: Data on water quantity and quality variables or the ecological state of water body/aquatic system, performance against a standard or environmental damages are written automatically into a blockchain ledger by smart metering devices. Making this process transparent and automatic has greatly improved the efficiency and type of regulation.

	low	high	
How **familiar** are you with this topic?			n/a
How **important** is this topic for the urban wastewater sector?			n/a
How **realistic** is the example Vision2030?			n/a
How **desirable** is the example Vision2030?			n/a

6.5 Global Changes

The increasing number of people who dwell in urban catchments and their behaviour affect the way urban wastewater systems are designed and managed.

Vision2030: Large scale migration, e.g. climate-related population movements from Africa to Europe, or pandemics, e.g. due to the H1N1, has a disruptive effect on urban wastewater systems that rely on their robustness and resilience to provide the (new) services the changing society desires.

	low	high	
How **familiar** are you with this topic?			n/a
How **important** is this topic for the urban wastewater sector?			n/a
How **realistic** is the example Vision2030?			n/a
How **desirable** is the example Vision2030?			n/a

SI 2 Participants and summary statistics

Who was contacted and who responded?

Invitations sent out 22-28 August 2017 to the following lists:

- IWA connect (KV, 28 August 2017)
- ICA2017 mailing list (PVR, 22 August 2017)
- WEF committees (PVR, 23 done August 2017)
- KV: MIA mailing list (KV, done)
- Urban drainage list (JR, 22 August 2017)
- Eawag communication, facebook (JR, done, 28 August 2017)
- Research Gate Project (PVR)
- Setup project homepage on Open Science Framework (JR, 22 August 2017)
- LinkedIN (KV, 28 August 2017)
- HSG (JR, 22 August 2017)
- VSA (KV < JR, 28 August 2017)
- IFAC (KV, 28 August 2017)
- UNLEASH water group (AS, 28 August 2017)

Reminder sent out on 8 September 2017: successful (33% extra response)

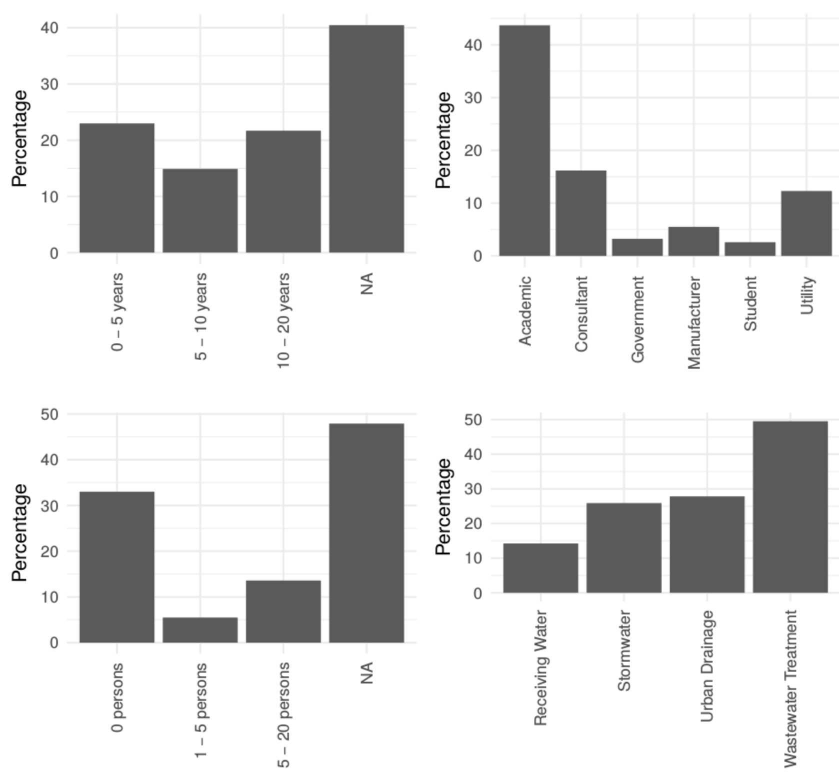


Figure SI 2.1. Summary statistics of respondents, **top left**: years of experience, **top right**: sector (students are only counted as student if "student" was the only option selected by the respondent), **bottom left**: number of people responsible for, **bottom right**: field of expertise

SI 3 Response behavior of respondents

Were all topics responded to in an equal manner?

We observe a distinct drop in the number of ‘complete responses’ of 25% for Theme 3 - “Interaction Data & Stakeholders” (see Fig. below). While the gradually decreasing response after Theme 4 may be attributed to the participant’s fatigue over the survey, we believe the lacking responses to averseness to respond to Theme 3 topics is due to the Theme’s context [3 - Interaction between Data and Stakeholders] and the fact that corresponding topics covered obviously sensitive aspects, such as ‘smart metering and privacy’, ‘cyber security’, ‘complexity vs. blind trust’. The in-depth analysis of individual, topic-specific comments (see Chapter 4) supports this hypothesis: some facets associated with the anticipated data plethora are perceived as potential threat, accepting that this interpretation is somewhat subjective. Contrary to this, the more reluctant and more heterogeneous response activity regarding Theme 6 [“Societal Values and Interaction”] is likely due to i) the “fatigue” aspect (last theme in the survey), and ii) the more regulatory-type of aspects that an engineering community may not be as familiar with.

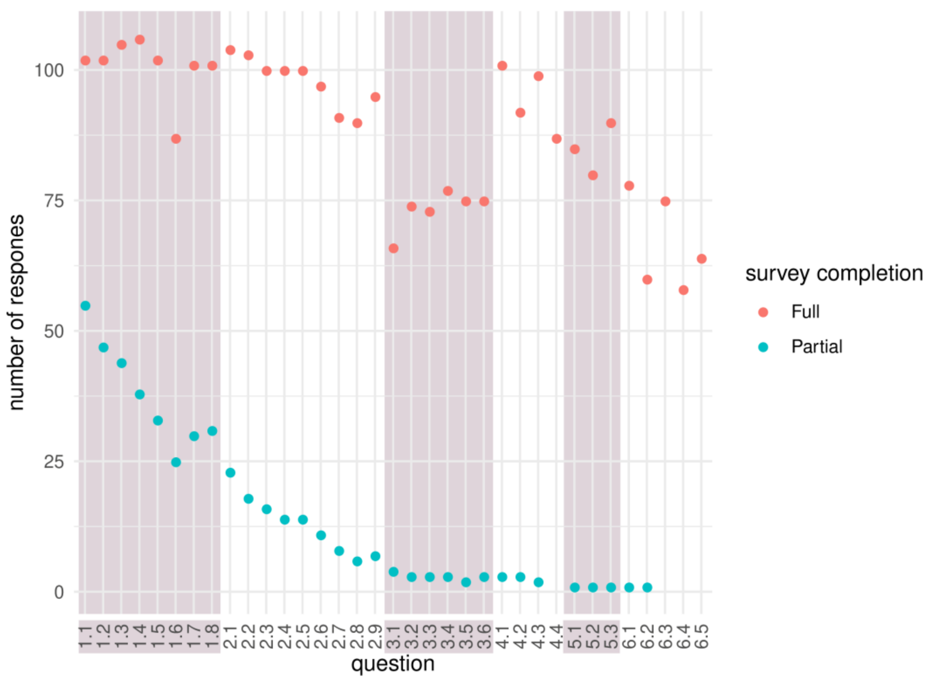


Figure SI 3.1. Number of responses for each topic (where both *importance* and *familiarity* was answered to determine *novelty*).

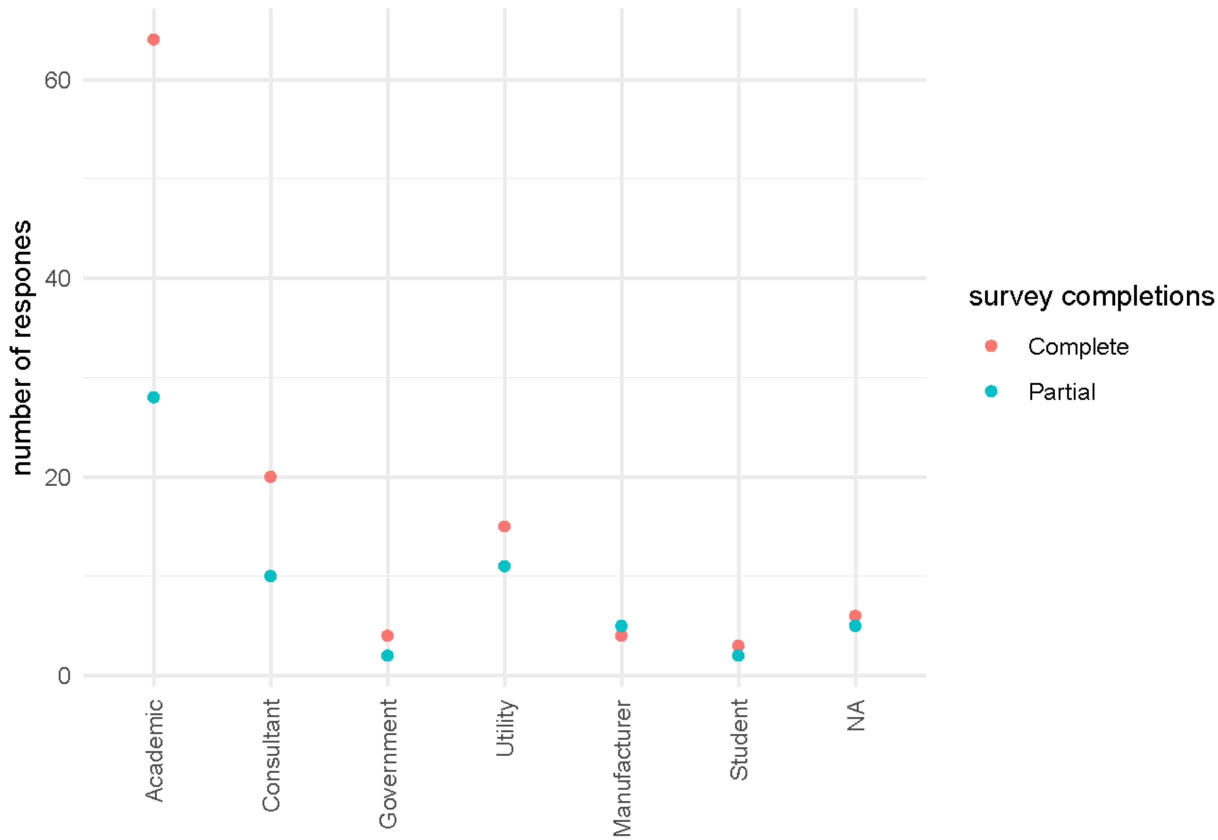


Figure SI 3.2. Response rate for full or partial completion of the survey depending on professional background**.**

SI 4 Responses for scenarios *Vision2030*

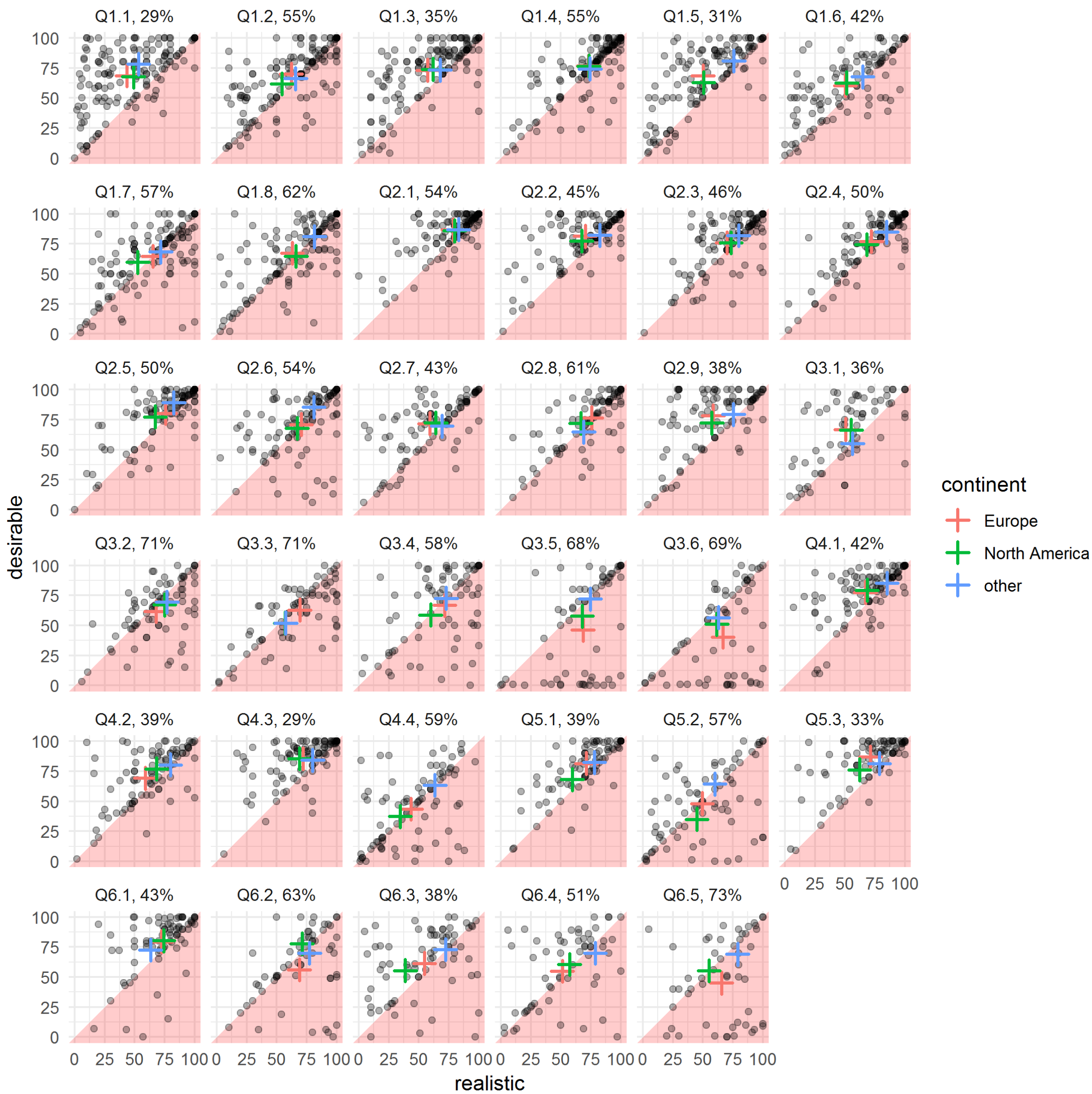


Figure SI 4.1. Graphical representation of responses for how realistic a scenario (Vision2030) is and how desirable it is. The red area indicates where *realistic* is higher than *desirable* (*feared* zone).

SI 5 Summary of comments from survey

Selection of a total of approx. 450 comments made by all participants

1 new topic
22 new aspect/vision to existing topic
90 substantial comment to existing topic
12 comment to improve methodology of survey
1 participant expects an answer from us

Comments per topic that at least two of the authors deemed relevant

Rank of 10 most **novel** topics	Topic title	Nr of new aspect/ vision to existing topic	Nr of sub-stantial comment to existing topic	Topic title	Rank of 10 most **im-portant** topics
1	2.9 Linking Aquatic Ecology to Emissions	1	2		9
2	2.7 Goal-Oriented Learning		1		
3	3.1 Ontologies		1		
4	3.5 Cybersecurity		1		7
5	1.5 Micropollutant and Pathogen Monitoring	3	5		
6	1.6 Environmental DNA	1	11		
7	3.6 Complexity – Blind Trust	2	3		
8	6.5 Global Changes				
9	5.1 Secondary Health Benefits				10
10	1.1 Onsite High-Resolution Mass Spectrometry	4	2		
		1	1	4.3 Integrated Management	1
		2	3	2.1 Data Validation	2
			1	6.1 Regulations	3
			3	5.3 Resource Recovery	4
			3	4.1 Decentralization	5
			5	2.5 Real-Time Models	6
				2.2 Metadata Collection and Organization	8
	1.2 AUTONOMOUS SENSOR PLATFORMS AND REMOTE SENSING		4		
	1.3 SENSING AT HIGH SPATIAL RESOLUTION	2	8		
	1.4 LOW-TECH SENSORS	1	7		
	1.7 IMPLICIT CROWDSOURCING	1			
	1.8 CITIZEN PARTICIPATION		2		
	2.3 OPTIMAL EXPERIMENTAL DESIGN	1	2		
	2.4 HETEROGENEOUS DATA QUALITY	1			
	2.6 DATA-DRIVEN MODELS		4		
	2.8 SOFTWARE SENSING		3		
	3.2 AUGMENTED REALITY		4		
	3.3 SERIOUS GAMES	2	5		
	3.4 SMART METERS AND PRIVACY		1		
	4.2 TECHNOLOGY DIVERSIFICATION		1		
	4.4 DATA COLLECTED AT PERSONAL RESOLUTION		2		
	6.2 INDEX BASED INSURANCES		1		
	6.3 WATER TARIFFS		2		
	6.4 TRANSPARENT COMPLIANCE ASSESSMENT		1		

1 new topic

g	id 288: Dear all, thanks you for your interesting initiative. The monitoring visions may sometimes remember on Huxley´s "brave new world". Keep cool with this ! The demand for cetainty and control seems natural to men. Uncertainty is hard to endure, but so are most of the other virtues. They offer sweet freedom ! **A further aspect is the over-engineering of everyday life.** Socrates' classic three questions may provide answers: Is it important? Is it correct? Is it good? It´s worth to reflect on that. Not the technically feasible, but the necessities should guide us. However, good luck for your further work. Ciao, xxx

22 new aspect / vision to an existing topic

1.1	id 196: This technology not only allows the monitoring of pollutants, but also the behavior of the people / industry in a catchment. Legal & illegal drug use, disinfectant, health aspects, ...
1.1	id 240: Although pollutants could be measured on-line with this equipments some problems related with the accuracy of the observations such us: - uncertainty in regression equations from the spectrometer and the target pollutans (e.g. determined with conventional analytical methods) - spatial variability of the pollutants (e.g. TSS concentrations are non-uniform in the flow depth) - an accurate measurment of flow is also needed to determine pollutant fluxes and masses (concentrations are important, but flow measurements are needed and most of the times are not easily determined in the sewers).
1.1	id 254: I suggest implementing passive samplers as a new monitoring tool that can be coupled to high resolution mass spectrometry.
1.1	id 285: It is not an alternative vision but rather a complementary approach: Ecotoxicological effects (e.g. of trace pollutants but also of other contaminants) can be measured online at almost any location at any time in any flux in order to be able to prevent negative impacts on surface waters. Ecotoxicological bioassays are implemented in regulation and are applied complementary to chemical analysis.
1.3	id 202: maybe this can include pollutant concentrations as well to identify areas with high I/I contribution or areas of concern with respect to illegal discharges from industrial facilities
1.3	id 210: Cities typ know where problems are, oonly need meters there. Could we eventually bill customers on sewer use not flat rate or water use.
1.4	id 335: Wireless sensors and floating sensors should be investigated. The first ones might offer some benefits: simple installation, better signal quality. The latest (together with the proper technology) might give a better measurement, reduce sensor clogging, problems with bad positioning.
1.5	id 239: How important is the impact of ongoing legislation on the applicability of these sensors? The point is that, even I consider it important, I am aware that many micropollutants (e.g., pharmaceuticals) are not included in legislation (maybe just a watch list of chemicals of concern by EU). Similar goes for antibiotic resistance - there are some actions planed by EU, but not really new legislation addressing this issue. Therefore, I consider rather ambitious to implement these advanced technologies in the urban water system, when utilities/companies are not forced to monitor these parameters. I think the review should reflect a bit on this aspects when talking about monitoring emerging contaminants.
1.5	id 247: A sensor network helps protecting the environment and ecosystem. But to become effective, governance structures are important too. Who is responsible for actions based on the sensor readings? What are actions are effective? How are they enforced? etc
1.5	id 285: I suggest to add ecotoxicological monitoring to assess mixture effects of micropollutants as well, this is especially important in order to protect ecosystem health, as chemical concentrations alone do not allow us to draw direct conclusions on ecotoxicological effects. Vision 2030: Flow-through methods for the online monitoring of ecotoxicologial effects are developed to such a degree that they can be easily applied and require only low maintenance. They are in place at key stations (e.g. at drinking water wells or in effluents of WWTPs) in order to prevent the usage / discharge of harmful water into the environment.

1.6	id 185: The predicted load should also be used to evaluate the data quality of sensors measuring in the influent
1.7	id 413: This topic go in line with the efficient use of the data within big data approaches, where the "power" of all the available data could be exploited to transform information in meaningful action . We see more and more this type of developments not only in the water sector but also in the energy sector for example. However, in a data framework strategy, there are other stages that need to be solved first like making sure all the data is first validated and trustworthy
2.1	id 149: Validation is important, so do the information provided by data. The information extracted from validated data might be more important to store than the data used to get it.
2.1	id 162: If we are looking at 2030, the algorithms need to be able to do much more than quality assessment. It should also be able to suggest what the problem might be with the sensor and take the data out of the control loop if relevant.
2.3	id 413: The ideal approach will be to come up with a benchmark solution, to help in the standardization of methods and required measurements for different intended applications...
2.4	id 169: *Mathematical methods retain error and uncertainty through to outputs such that uncertainty accompanies each output. Results are interpreted within context of estimate and error, rather than exact value.*
2.9	id 166: Alternative: The precautionary principle asks for physical - chemical thresholds that prevent harm. Finding consensus on "desired ecosystem make-up" is challenging and ecosystems may evolve due to pressures other than urban water outflows.
3.3	id 162: Gaming for training of water professionals might be very interesting. Also as a means to bridge the age-gap. How could this be done to extend the competence of currently employed persons in the direction of Smart Water Utilities and/or ecological understanding?
3.3	id 182: Serious games could be useful for testing if e.g. an MPC scheme can beat the operators, and thereby convince the operators that the MPC is trustworthy.
3.6	id 166: Time constant different than in an airplane. Also - the decision structure changes when normal routine is taking off into an emergency (Houston August 2017) . Not clear what "desirable" means in this context.
3.6	id 272: I agree, see also my comments on acquiring certain type of data and the blind belief in models, we should try to find out how to balance technological and human interference regarding the systems discussed here.
4.3	id 212: In reality, the nutrient part of the equation is more impacted by farming (and possibly lawn care) than by urban wastewater treatment. It may be more cost effective for bubble permits to be established and have cities pay farmers to establish buffer zones, rather than to implement increasingly strict nutrient limits at the plant level where we as citizens are not getting the biggest bang for the buck. A certain level of nutrient limit is good, because if forces a plant to be energy efficient, but there are reasonable limits beyond which regulating the treatment plants effluent limits is economically counterproductive.

90	substantial comment to existing topic
g	id 413: Interesting and key topics being addressed and solutions being proposed to deal with current and future challenges in the water and wastewater sector as data as main driver. While processes and sensor technologies are already mature, the power of the data being collected is needing to be efficiently exploited within monitoring, control and decision making applications. Looking forward to see the results of this initiative and discover the progress direction of the years to come...
1.1	id 186: it is already happening, f.i. control in the sewersystem or influent on pH as prevention for early warning of drugs waste dumping in the sewersystem. Being able to measure specific chemical compounds is desirable in this respect
1.1	id 247: An alternative/supplemental monitoring strategy would be based on bio essays. In that wat a direct effect of the presence of pollutants can be identified
1.2	id 162: Active robots scans the sewers and repair damages either by itself or calls for repair robots. In this way e.g. H2S problems are handled very soon.
1.2	id 285: Autonomous sensor platforms are, amongst others, able to record chemical as well as ecotoxicological parameters and can thus sense and report pollution events or polluted sites. This enables a fast reaction to such an event. An example for such an existing sensor platform is the "Envirobot" (http://www.nano-tera.ch/projects/345.php).
1.2	id 295: An autonomously and continuously operated fleet of robots is too optimistic as a vision. Instead, there are companies that rent out active and passive robots for exploration and measurement. They are used by academics to better quantify uncertainty due to lack of understanding and by practicioners to execute troubleshooting tasks. These are a small fleet of robots that are actively maintained for such time-limited tasks.
1.2	id 360: At my utility, although we do investigate and purchase new sensors, our greatest challenge and our current focus is on improving our stewardship of the data we are already collecting (data validation, sensor maintenance, responding more quickly to errors, improving our process for selecting new instruments, making meaningful use of our existing data). Technologies which involve collecting more data are not a focus now and I feel like for us the vision2030 is more than 15 years away.
1.3	id 139: Flood warning is imo not likely to be improved by just increasing the number of sensors: For rivers, predictions based on existing (river) sensors exist and are reliable. For sewers, measurements from within the network would hardly help as their lead time is too small. (RELIABLE rainfall forecast would be VERY desirable) For system control the amount of sensors could never be too high, as long as data treatment can handle the amount of data, retrieve relevant(!) information and this information is not rendered useless by a too limited amount of actuators.
1.3	id 149: Hydraulic and Hydrology modelling enables the use of less sensors to monitor complex networks. I do not believe dense networks of sensors are desirable, as they will require always further maintenance. I believe the number of sensors is dependent on the requirements o calibrate hydraulic models. E.g in the U.K. all water utilities have tried systems modelled with xxx and this should be the target.
1.3	id 155: There is a balance of need and desirability. There is already a lot of data collected in the industry, but much of this data is not exploited. I think what we should learn to measure what we really need to result in valuable information. Yes, the more we measure, the more data we will want. The technology in this field is already there, but emerging.
1.3	id 194: Sensors at every manhole can be an overkill for most applications and will be a huge maintenance cost for any reliable information from them. Instead, sensors that are robust (less maintenance) and provide high quality data will be highly desirable.
1.3	id 198: collect all sewer data in a huge data ware house countrywide to make a standard measurment including maintenance, automatic data validation, alerts for non working systems and let it be accessible for research and government. Besides build up sensor measurment standarts for CSO's and include this data too.
1.3	id 243: The use of API for real-time rainfall data, or cell phone activity/status/temperature for peak

	load prevention might be more realistic and less maintenance requiring than equipping every manhole with a sensor
1.3	id 247: A sensor network needs optimisation. Putting equipment in every manhole does not provide additional information of the specific events mentioned. A more optimised network in relation to spatio-temporal resolution of the events to be measured is more effective.
1.3	id 413: This will be the "ideal" situation, having data in-real time from every manhole at the cities, that could allow a fast reactivity and control of the sewer network and also control of the load to treatment plant facilities, what at the end will impact the receiving body in an integrated control perspective. In this point the key will be the on-line treatment and analysis of the data to be able transforming this data in useful information immediately (prediction models, remote control, alarm systems...)
1.4	id 139: It would be interesting to know what kind of sensors (for which variables) are envisaged. Energy consumption for simple level sensors is much smaller than for data communication. They are reliable and cheap but deliver relevant information. --> No need to oversimplify those. For anything water quality related, more robust, cheaper, simpler sensors requiring less maintenance would be one of the most important aspects for improved systems analysis and management in urban drainage.
1.4	id 149: I think low cost sensores can be helpful for small water utilities, but not so important for larger companies. In this case, the cost of sensors is nothing comparing to the overall cost of implementing systems such as Flood Forecasting System. In addition, if a very complex system is implemented, high resolution data will be required with very high resileance.
1.4	id 186: there is a drive for small scale treatment to save on high costs of sewer infra, this becomes more realistic with low-tech sensors
1.4	id 263: Digital switches are more reliable that transmitters with 4-20mA. Also the data loading in the DCS side will be minimal compared to transmitters. The signal transmission will be fast and losses will not effect the result.
1.4	id 287: Robustness is key in this aspect. The use of cheap and robust sensors seem much more desirable to me than high tech-high maintenance sensors
1.4	id 291: In principle this may be possible but will require significant data analysis efforts and subsequently operation/maintenance of the dense sensor grid. So this will be done only where a need is identified, e.g. severe local water on street problems.
1.4	id 413: Totally agree with this vision. In fact this will be the most cost effective strategy to be deployed all around sewer networks where robustness, deployment and energy autonomy are the main concerns. Both types of sensors are complementary and they could be used in a multi-layer on-line monitoring strategy where data could be then combined in univariate and multivariate analysis for several applications.
1.5	id 212: The example of online flow cytometry may bias results. This particular technology might be more applicable to water than to wastewater or stormwater. If online pathogen detection could be developed for effluent which confirmed permit compliance, that would be useful. Micropollutants do not need to be analyzed for continuously.
1.5	id 247: A sensor network helps protecting the environment and ecosystem. But to become effective, governance structures are important too. Who is responsible for actions based on the sensor readings? What are actions are effective? How are they enforced? etc
1.5	id 259: Pathogen monitoring in the sewers would be a very interesting way to obtain early warning systems, not only for the WRRP but also for the hospitals and health authorities in the city.
1.5	id 272: From a range of perspectives this seems to be bit far-fetched , apart from the technological and management issues, I feel monitoring at source level is far more effective. At the same time, again, this type of data-collection has a potential of privacy loss. Another issue: how to communicate the results, while avoiding panic, or risking that certain urban areas to be regarded as 'no-go' areas?
1.5	id 413: Although the need is there for on-line monitoring of micropollutants and metals (and such need will increase more and more in years to come), the technology in my opinion is not totally

	ready to face the challenges of the hard measurement conditions found in the wastewater environments for example. Some applications are currently in development based on images or even spectrometry, and industrial sensors are now available for drinking water applications, but a lot of effort is still required to make this technology robust and really suitable for more complex environments...
1.6	id 166: If eDNA is the answer, what was the question?
1.6	id 271: Problem with eDNA is that it measures the integral of all ecosystems that the water has been subjected to. So, we can't assess locally what the impact of pollution is. For that we would need to have RNA analysis or something.
1.6	id 281: So far gene probe information has not delivered much at the engineering scale. Useful at the scientific level, but even then it can end up as stamp collecting rather than exploitable insight.
1.6	id 285: In addition to monitoring with environmental DNA, the composition of ecosystems is also monitored with taxonomic methods from time to time, in order to verify the molecular methods and to not loose the taxonomic knowledge. Also the plausibility of the data should be checked along with the measurements. In addition, it is important to know which part of the eDNA is coming from the wastewater (e.g. from humans...) and which part is from the organisms in the river.
1.6	id 413: While monitoring of physical-chemicals parameters has reached a certain degree of maturity, it is true that current tendency is focused in biological sensors, where more deep information about bacteria and microorganisms could be obtained. However, and in relation to the previous question as well, efforts should be focused in making those technologies suitable and robust enough. I see here a need for a strong collaboration between researchers and sensors &technology suppliers...
1.7	id 168: In addition... the legal, privacy, public perception/acceptance and liability issues associated with collecting this data have been thoroughly explored and assessed.
1.7	id 247: An alternative source of data is the 'white good sector'. Many washing machines, dishwashers etc have sensors on board to control the washing process. These data could be tapped to give additional information on discharge water quality, volume and time
1.7	id 272: I have my doubts, RTC is a largely unfulfilled promise over the last 30 years, especially model predictive controle is more of a toy for scientists than a realistic practical instrument. Maybe a data driven approach can alter this, at the same time we'll need to built and operate these systems in a very robust manner, relying to much on vulnerable systems implies a risk. Therefor I suggest to perform a realistic riskanalysis on this idea .
1.7	id 281: Cost of data acquisition, security of data acquisition, ensuring that it is not exploited to provide information at the individual level, provision of useful sensors, these will be barriers. But the idea of more data, available rapidly, has been a dream since the 1970s if not earlier. However, the dominant response times in wastewater systems may mean that this data cannot influence process changes in time to avoid (rather than mitigate) pollution events.
1.7	id 291: For dry weather, we have quite good forecasts already. For wet weather, I am not sure about the performace improvement by applying this info in feedforward control. Might be usefull for energy optimization and peak shaving (especally NH4) at WRRF's
1.7	id 360: Interesting idea! It is difficult for me to envision this in our utility. Our plants are so large that pollutant loads and flows are very stable regardless of the movement of people in and out of the City or their travels within the City. I can see spatially distributed data being used more for optimizing drinking water delivery...
1.8	id 281: Sexier fields - extraterrestial signals, sea ecology - have had low rates of uptake. Water companies can be censored if their own information systems cannot provide data more rapidly than the public, as it is seen as a sign that they are not paying enough attention to their own process control and monitoring.
1.8	id 287: The importance of this tool is not only better monitoring but mostly the greater public engagement and awareness.
2.1	id 285: Comment: I think not everything can and should be replaced by automatic data evaluation.

	Also expert knowledge should still play a role.
2.1	id 295: Despite the tremendous amount of research and opportunity for automation, data quality evaluation remains very hard to automate. This is in part due to the fact that certain measurement deviations are extremely hard to detect without manual check of laboratory reference measurements. Instead, my vision is that the industry adopts a pro-active maintenance strategies which aim to predict the outcome of a manual check or reference test and automatically assign tasks to technicians to minimize the frequency by which manual checks and/or reference measurements lead to a failed quality test.
2.1	id 413: I totally agree this this vision, and in fact data validation is the key for efficient monitoring approaches. However, most of the available methods today are still manual and the challenge here is transforming the current research developments based on mathematical algorithms in practical tools to be used in a regular an daily basis
2.2	id 175: Several standards already exist. Data management and analysis tools must be able to deal with a universe of ad-hoc data standards. Perhaps we should encourage the adoption of open-architecture and open-source standards.
2.3	id 169: Models inform how cost- and time-effective measurement campaigns should be conducted to answer the posed measurement question. Data with the highest possible information content for that purpose are obtained. *Accuracy and structured design sampling reduce uncertainty to pre-selected levels.*
2.3	id 315: This vision encounters the problem of having good models and good models prediction (which are key to a good prediction of information richness in nonlinear models). I think that this will not be solved easily
2.5	id 240: In order to apply this surrogate models advances in data acquisition and validations are also needed
2.5	id 259: The challenge is to establish identifiability conditions and sufficient system excitation to update or derive the real time models.
2.5	id 272: All models are basically lies, the complexity of the processes involved along with the ever increasing demand for information will never be covered by models. Further, I feel that we should not rely too much on what models will bring us, we've some nasty examples in the past: people using models far beyond the validated envelope etc. I'm afraid this is not changed by 2030.
2.5	id 291: I think more improtant for surface water managment (hydrological models) than for the urban wastewater system. For prediction downstream water quality e.a. for swimming is desirable and we are working on this.
2.6	id 166: Vision sounds fluffy. If decisions are taken based on models with "less system understanding" then we are walking on thin ice.
2.6	id 208: Although I consider research in this area very important and the formulated vision realistic, I don't think data-based models should ever completely replace mechanistic ones. As far as I can tell, they indeed require less system understanding, but also yield less information on the system when needed. They are perfect for predictions and control, but not for technology development or building process knowledge required to disruptively advance technology.
2.6	id 291: I think use will increase, but in my opinion application without understanding the underlying pehnomena and structure and especiaaly range of model validity is not a thing to do when exprapolatiing outisde models validity range. In genera, it seems many data scientists use their bag of tools without being aware of (principal) limitations.
2.6	id 312: the vision explicitly abandons mechanistic models, which is not good. We should keep and refine the mechanistic models and use the data-driven things for complementary or other tasks. Especially for extrapolation beyond the training data.
2.7	id 166: Caveat: Keep the artificial intelligence under supervision by an intelligent brain.
2.8	id 259: Maybe the software sensors should not replace hardware sensors. Rather they will exhaust the information from available hardware sensors.

2.8	id 295: Increased use of soft-sensors leads to the realization that the data fed to the models is fairly uncertain and needs better spatial and temporal resolution. This drives the installation of additional sensors to improve model predictions to the targeted level of confidence. Just like desk-top computers induced an increase production of printed documents and use of paper, soft-sensors will induce more use of sensors and generation of raw input data.
2.8	id 413: Many parameters that are being required or desired today for on-line monitoring (but still not technically available) could in fact be measured using "subrrogate" parameters as a combina-tion of already available sensors thanks to model approaches. Future is there for a considerable number of crucial parameters today, what can also lead to reduction of capex and opex costs
2.9	id 281: Environmentally damaging solutions are being requested by looking at only one disposal route.
2.9	id 285: Comment: As aquatic ecosystems are very complex, I am not really sure how well this vision can be reached. I was also not sure what you mean with ecosystem make-up. In addition it is important to discuss about who is defining the desired ecosystem make-up and how it should be reached.
3.1	id 166: The diversity of citizens requires complementary approaches, one formal ontology will not do.
3.2	id 162: It might be more interesting to be able to look into the aquatic environment of the recipients to see and experience the effects of water pollution incidents.
3.2	id 212: Continued gathering of existing infrastructure location and depth so that GIS systems can be made more accurate to (i) helps city planners knowing system components location, (ii) helps showing the condition of urban water assets to the system managers, and (iii) provides a way to engage with citizens and motivate them for the infrastructure's importance.
3.2	id 272: God idea, although I have some doubts on 'engaging citizens', most citizens I know are of the type 'flush and forget' and 'complain when flooded', let's be realistic: most people don't have time nor interest in this, urban drainage and wastewater systems simply have to their job without bothering people.
3.2	id 281: This was being made commercially available in the 1990s, but then fell away - presumably because it was seen as a gimmick. But it has already been used to ensure that access is available when designing sewage works, and to visualise 3D simulations.
3.3	id 259: I doubt if this will be used by the general public. However, for operator training and to cre-ate an awareness in the management it may be a very important development.
3.3	id 281: For professionals, this will work. For the public, less so. We will need games designers and more support from the social sciences / psychologists for this to take off.
3.3	id 285: Comment: I am not sure how well such games can complement or replace learning by e.g. visiting a facility or experiencing processes by experimentation. However, it might be a good com-plement to real-world learning.
3.3	id 291: Question is if the public is the main stakeholder or that serious gaming should focus on decision makers-stakholders.
3.3	id 315: As with other common goods, the result of aggregating individual preferences is not nece-sarily society preferences. Hence, serious games and other communication actions can be used to raise awareness about the impact of consumer actions and their consequences
3.4	id 312: the vision is negative for me. The fact that data only being used for predefined purposes would not make it possible to harvest its full potential. Say using water-quality data only to improve the conditions for the aquatic environment and not analyse them for community health services. Or cell phone antennas for rainfall monitoring. Or satellite data for google maps. The *really* big potential of IoT is that data are used across silos. How do you protect privacy: currently unknown. Most possible through blockchain technology...
3.5	id 196: The vision is not very desirably formulated -> therefore desirability = 0! Fundamentally, this is not an problem that UWM can solve - but that needs to be addressed for almost all public infra-structures - including health services, energy, ... The vision would be that cyber security is a key

	aspect in the Vision 2030.
3.6	id 162: We recently experienced a fire in an industrial oil facility and had to deal with the fire-fighting water. This water was potentially polluted with untill then never seen before chemicals - and the time to analyse the situation for different options were limited. This required a good knowledge of the way the system could be tweaked. This will be difficult to do in an automatic way.
3.6	id 175: This is an observation of the status quo. In the future, automated formal tools will be used to design systems to gracefully enact contingency actions that arise from unforeseen circumstances
3.6	id 285: Comment: I guess in order to avoid the consequences of such rare events, we should find a good balance between automation and control by real persons, e.g. operators.
4.1	id 169: The urban water infrastructure consists of decentralized process units that are controlled intelligently via remote monitoring and centralized operation and optimization. Given that technicians cannot inspect every decentralized unit with the same frequency as is typical for full-scale plants, the decentralized process units are highly autonomous to reduce downtime and maintenance costs. *Predictive maintenance schedules based on monitoring that reduces uncertainty and costs.*
4.1	id 239: My concern is not about how realistic is to get good monitoring tools for decentralized systems, but how realistic is to expect that a large part of the urban water systems will become decentralized in the close future. Sure, there are some industries/industrial parks or even households treating their own wastewater before discharging it to the sewer, but how representative is the load treated in these systems compared to the load treated in centralized treatment plants? Will it be decentralized treatment a trend in the upcoming years? I think before jumping into monitoring this should be addressed.
4.1	id 259: We will see more decentralized systems, not only in new subdivisions but also in many peri-urban areas, particularly in rapidly growing cities in the developing world. Decentralized energy (solar PV and wind) will make this possible. It will require a high degree of automation of the individual plants, completed with communication to professional operators and process engineers.
4.2	id 239: I think the review should actually cover if the lack of proper monitoring and control systems is hindering the implementation of novel technologies, e.g., for resource recovery, or other factors have a larger influence (e.g., market demand of products in resource recovery, technical issues, etc.)
4.3	id 272: I miss the topic 'public health' in your multi-objectives ;-)
4.4	id 264: I guess the importance of this becomes significantly higher if we are talking about decentralised systems, connected to a few houses or buildings. If the wastewater is sent to a large centralised WWRRF, then 'average' values might do the trick?
4.4	id 281: Aggregated treatment systems can work with modest average community data; down to the personal level is unlikely to provide the benefits compared to the intrusion in lifestyle.
5.3	id 196: From a global perspective there is one highly relevant ressources in wastewater: water. This will dominate the ressource recovery vision of future UWM. The rest only can be managed efficiently by measures at the source (e.g. heat recovery, urine) due to the high entropy.
5.3	id 239: It would be interesting to explain how to change the perception from society about wastewater. Do we need more education of the citizen? At what level? Just providing information would be enough? Which information is the citizen lacking, so he/she can become confident on consuming recovered resources? Many people understand the issue of resource recovery and think it is beneficial to recover resources. However, when it comes to the reuse they are not willing to consume re-used water or crops grown in effluent wastewater (there are some interesting reviews on this). Can the water sector face this issue by itself or needs help from social scientists?
5.3	id 298: I like this prediction, my only concern is that the cost of recovering resources from wastewater is too much higher than finding or creating new sources.

6.1	id 212: The economic impacts should be considered in a holistic fashion for an entire watershed. Farming has a far greater impact on watersheds in many cases than treated urban wastewater, yet this sector is largely unregulated. It may be less expensive for cities to pay farmers to provide buffer zones that will have a greater impact on nutrient reduction than to provide very advanced centralized wastewater treatment facilities for nutrient removal. Regulators should be flexible and allow for an economic solution that attains the desired goal.
6.2	id 264: A higher insurance premium when you build in a flood prone area is already in place in Belgium
6.3	id 155: The difficulty in variable tariffs in the water business is that the variable cost is small compared to the fixed costs. Optimizing the variable cost only affects a fraction of a utility's costs.
6.3	id 315: The consequences could be way worse than the benefits. If the prices become high enough (or they will not have any discriminatory power on behaviour), it could lead to people not using the sanitation (throwing wastewater away, or in a garden) just to avoid high tariffs, thereby creating a public health issue that had been solved in western countries many many years ago
6.4	id 391: Blockchains are not the only option and may not be the most desirable one..

12 comment to improve methodology of survey	
g	id 127: The survey takes a long time to go through and it was not possible for me to do it all at once. It would have been good to be able to re-visit the different sections at the end, to tune individual answers so they fit with the general picture.
g	id 285: I hope the comments are helpful. In general many topics of the survey seemed quite complex for me. As I am a biologist with the main focus in ecotoxicology and ecology, I have not much knowledge in several of the topics. Therefore I am not sure how realistic my estimations are. This should be kept in mind for the evaluation.
g	id 374: I had a hard time understanding the questions. A few more examples could have helped me.
2.4	id 127: Just a comment: This vision is very linked to 1.3 and 1.4 and, for me, 1.3 and 1.4 makes no sense without modelling/the use of statistics of some kind. Also, this vision is not possible without the sensors being available first.
2.5	id 149: I would just add understanding modelling uncertainty for the vision. Models already provide useful information, but are not widely spread. What is missing in models is understanding their uncertainty, as eximplefied in the description.
2.6	id 166: Vision sounds fluffy. If decisions are taken based on models with "less system understanding" then we are walking on thin ice.
2.8	id 212: Description is not well stated. Is this like taking pump rpm and power and interpreting an operating point (similar for high speed blowers?)
2.8	id 312: I do not see a real difference between software sensor and data-driven model. should be merged.
2.8	id 408: Not sure how different this is conceptually from any simulation model ...
2.9	id 285: Comment: As aquatic ecosystems are very complex, I am not really sure how well this vision can be reached. I was also not sure what you mean with ecosystem make-up. In addition it is important to discuss about who is defining the desired ecosystem make-up and how it should be reached.
3.5	id 152: The statement above is not currently phrased as a vision, but a threat. How about: Given the trend to more digitalisation, utilities have taken steps working in partnership with cyber security industry leaders to reduce vulnerability to cyber attacks and the attendant threat of blackmail to shut down operations. Also, i'm not sure how big a threat this is really, so NA on the individual questions.
3.5	id 196: The vision is not very desirably formulated -> therefore desirability = 0! Fundamentally, this is not an problem that UWM can solve - but that needs to be addressed for almost all public infrastructures - including health services, energy, ... The vision would be that cyber security is a key aspect in the Vision 2030.

1 participant expects an answer from us	
g	id 169: Could I receive the entire list of questions?

SI 6 Responses for importance & familiarity

Figure SI 6.1. Graphical representation of responses for familiarity vs. importance, differentiated after the correspondents' professional background (academic / non-academic). The grey area indicates where *familiarity* is higher than *importance* (*novelty* zone). Cross markers represent the mean response per sector (academic vs. non-academic).

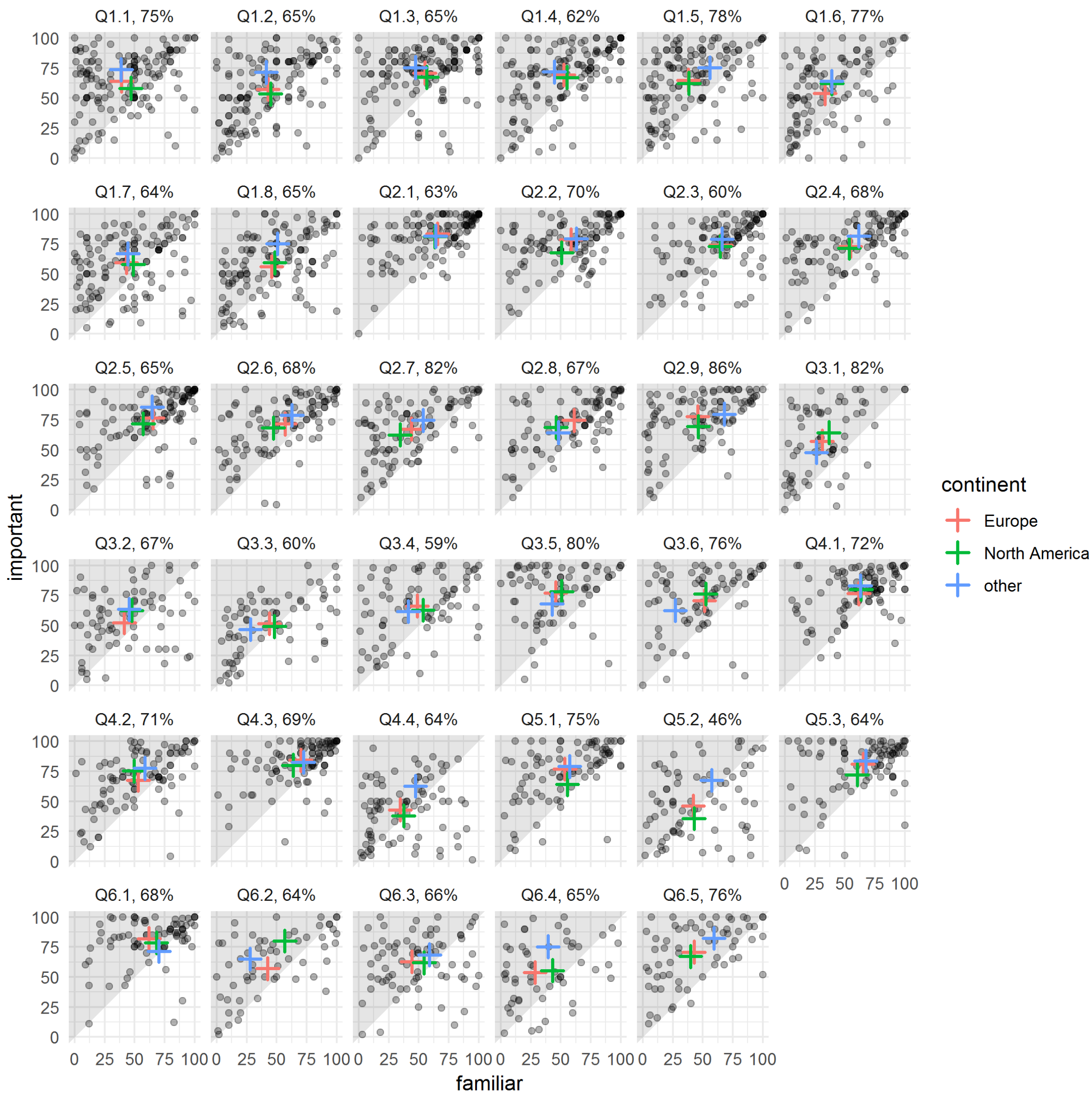


Figure SI 6.2. Graphical representation of responses for familiarity vs. importance, differentiated after geographical origin of respondents. The grey area indicates where *familiarity* is higher than *importance* (*novelty* zone). Cross markers represent the mean response per continent.

SI 7 Correlation analysis to discuss thematic proximity

In order to evaluate whether thematic proximity affects the ranking of the correspondents' responses – most importantly for the topics ranked top ten – we correlated response scores topic-by-topic (35 x 35) resulting in 595 pairs.

Following the hypothesis that an interdependence leads to a biased response behavior, we could expect a high correlation for these cases. For instance, respondents assigning a high score for Micropollutant and pathogen monitoring (1.5 – rank 5) may also do so for Onsite High-Resolution Mass Spectrometry (1.1 – rank 10), since the emerging monitoring technique appears as a subset of micropollutant monitoring. Despite thematic proximity, we decided to discuss both topics individually, since we saw a relevance for each topic on its own. The generally relevant aspects of micropollutants in aquatic environments is so covered at different levels.

The results of the correlation analysis show that, in particular for the top-ten ranked topics, the responses to questions on both, 'familiarity' and 'importance' are uncorrelated (see Figure 7.1, 7.2). In the context of the example above (1.1 vs. 1.5), the Pearson correlation coefficient is 0.55 ('familiarity') and 0.48 ('importance'), both well within the interquartile range of correlations for all 595 pairs (see Figure 7.3). This means, respondents who find that the overarching topic Micropollutant and pathogen monitoring (1.5) is relevant/known, do not necessarily believe that this is also the case for onsite HRMS (1.1), despite the given thematic similarity. Interestingly, the topics Reinforcement Learning (2.7) and Ontologies (3.1) with rather little thematic overlap correlate to a higher extent, at least for 'familiarity'.

On the other hand, for few very similar topics (e.g., 1.3 and 1.4) increased correlation coefficients for the 'familiarity' question support the hypothesis of a biased response behavior due to thematic similarity. This indicates the potential that particularly topics in Themes 1 and 2 should be reviewed and consolidated when including them in future foresight studies.

Overall, we can conclude: despite some thematic similarity, response scores are uncorrelated for the majority of the topics. In particular, the topics ranked top ten are very diverse and uncorrelated. The selection of the ten most emerging topics remains unaffected.

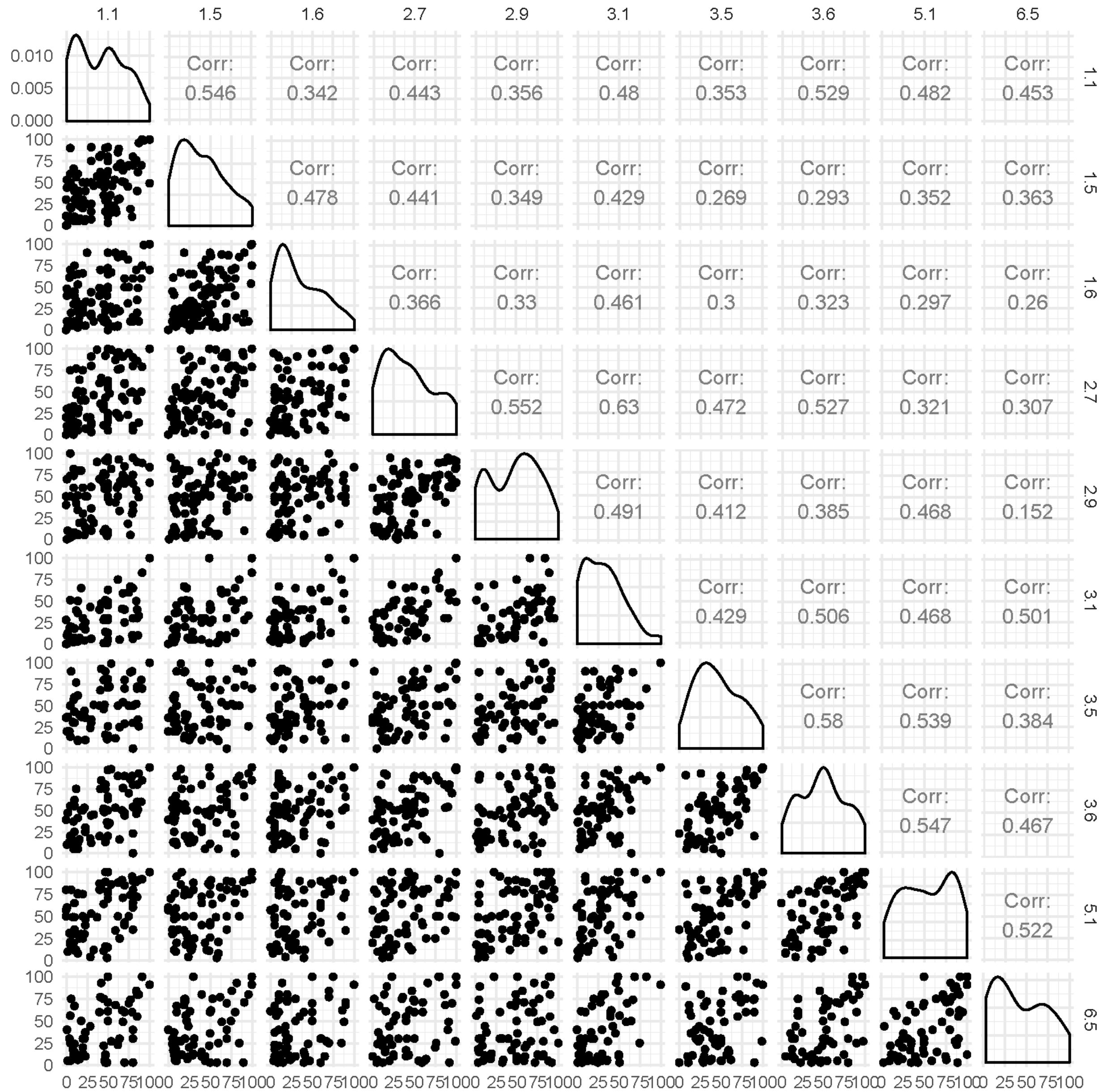


Figure SI 7.1. Correlation matrix for topics ranked top-ten regarding questions related to ‘familiarity’

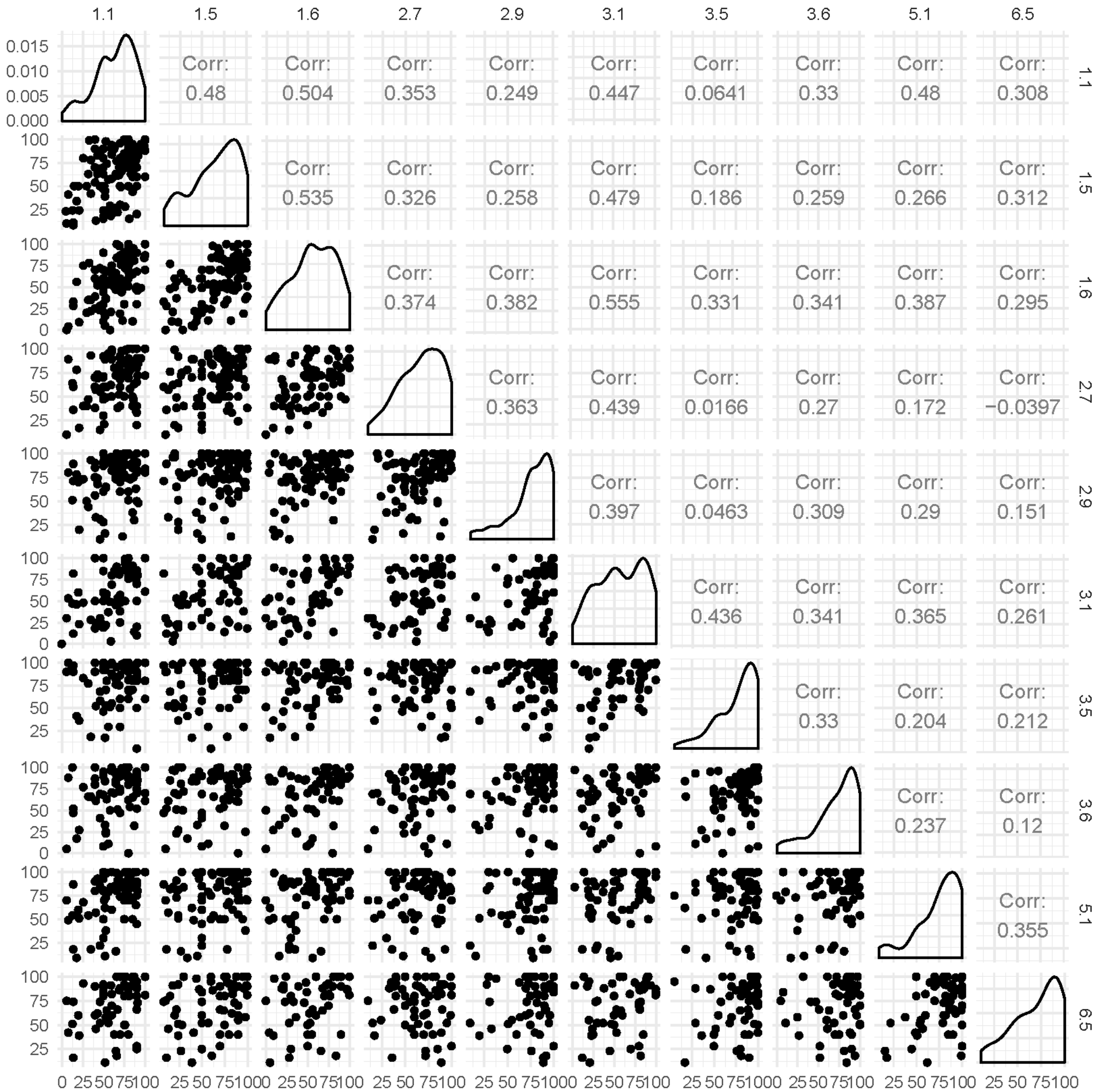


Figure SI 7.2. Correlation matrix for topics ranked top-ten regarding questions related to 'importance'

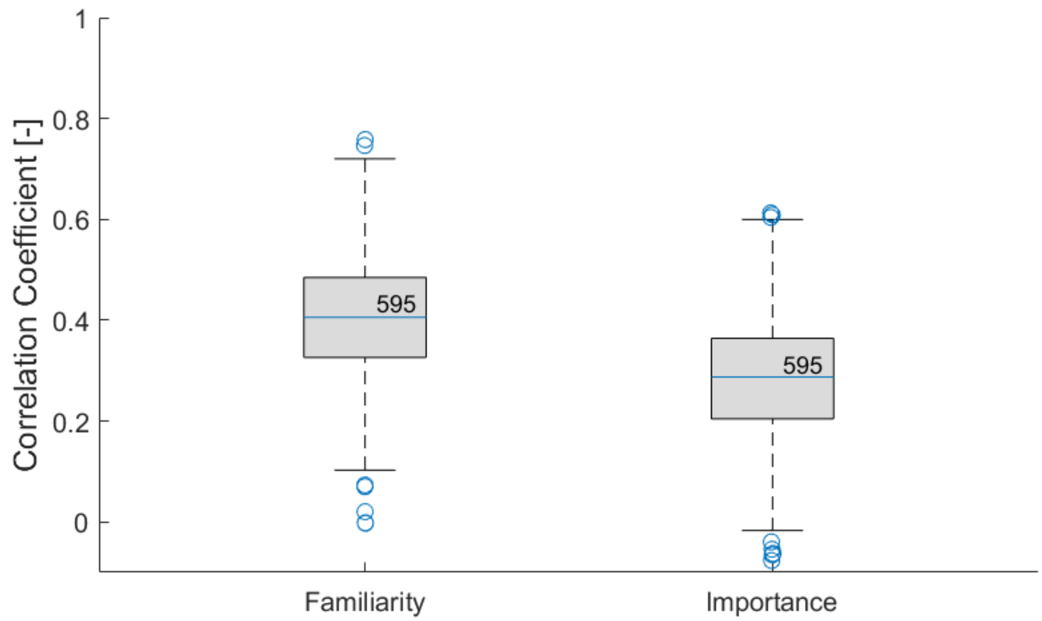


Figure SI 7.3. Variation of correlation coefficients for the pairwise comparison of responses regarding ‘familiarity’ (left) and ‘importance’ right for 35 topics (595 pairs). The grey box in the box plot represents the interquartile range, i.e. 50% of all values.